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STUDY TO DETERMINE DIELECTRIC PROPERTIES OF SANDSTONE, SHALE, COAL, AND SLATE

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The scope of work for this study was as follows:

(1) Perform triplicate dielectric constant and loss tangent measurements at 1, 10, and 100 MHz and 1, 2, and 10 GHz frequencies on samples of sandstone, shale, coal, and slate.

(2) Machine one samples each of the three necessary configurations of the coal material to obtain measurements at 1, 10, and 100 MHz and 1, 2, and 10 GHz, with each sample machined parallel to the coal layering orientation.

(3) Machine coal samples perpendicular to coal layering and perform measurements.

(4) Condition the six coal samples of paragraphs (2) and (3) at approximately 100% relative humidity and at room temperature for a minimum of 48 hours and remeasure dielectric properties (12 measurements).

(5) Condition the six samples in an elevated environment not to exceed 110°C for a minimum of 48 hours and remeasure dielectric properties (12 measurements).

The samples were received from NASA in bulk form and were mailed by us to Quartzite Processing, Inc., for machining and grinding. Three each of sample 3 types were machined for the 1, 10, and 100 MHz measurements. These samples were 1.125 inches in diameter and approximately 0.125 inch thickness.

The slate material could not be machined because of crumbling. Three each of 3 sample types were machined in a coaxial configuration for the 1 and 2 GHz measurements. Three each of the samples were machined to RG-52U waveguide dimensions for the 10 GHz measurements. Additional samples of coal were machined for the parallel- and perpendicular-to layering configurations. (As previously stated, the slate material could not be machined.)

The 1, 10, and 100 MHz measurements were peformed utilizing Test Method A-STM Designation D 150-59 entitled "A-C Capacitance, Dielectric Constant, and Loss Characteristics of Electrical Insulating Materials." A standard impedance bridge was used in conjunction with a variable air capacitor/sample holder.

A known disadvantage of this type technique is that good contact must be made between the sample and air capacitor plates when the sample is inserted into the holder. This particular problem was resolved by using very thin platinum foil so that good electrical contact was maintained between the sample and the capacitor plates.

The 1 and 2 GHz measurements were performed by use of the coaxial short-circuited transmission line technique. The sample is machined to fit a coaxial sample holder. Slotted line data are taken on the short-circuited coaxial sample holder with no sample and then with the sample placed against the short circuit. This technique is simple to instrument and the dielectric constant is determined within $\pm$ 1 percent accuracy.

The 10 GHz data were obtained by the short-circuited waveguide technique. The measurements are the same as the short-circuit coaxial line method. There is a slight difference in the calculations that were performed since the waveguide wavelength is different than that of the coaxial (air) line.

Since it was not possible to machine the slate samples, it was decided to obtain powdered sample data and to extrapolate these data to a typical 100 percent dense material. The density of the solid slate sample was measured to be 2.11 gm/cc. The 1, 2, and 10 GHz measurements were performed on powdered slate with densities that ranged from 0.95 gms/cc to 1.72 gm/cc. The log mixing formula was then used to determine the dielectric constant of the solid slate sample. This equation is:

$$\varepsilon_p = \varepsilon_{100}^{\,d_p/d_{100}}$$

where

ε_p = dielectric constant of powdered sample at density d_p

d_p = density of powdered sample

d_{100} = bulk density of solid sample

ε_{100} = relative dielectric constant of solid slate sample

The 1, 10, and 100 MHz measurements on slate powders were performed by the use of the vector impedance meter. The slate powder was packed at approximately the same range of densities as for the higher frequency measurements. The data on slate of Table I were extrapolated from these data.

The calculated data are listed in Tables I and II. The parallel and perpendicular data of Table II indicate the cases where the electric field is either parallel or perpendicular to the coal layering structure. The wet sample data of Table II indicates measurements taken on samples that were conditioned at 100% relative humidity for 60 hours. These samples were then baked out at a temperature of 100°C for 60 hours and the measurements were repeated (dry sample data).

In summary, the coal data appear to remain relatively constant over the microwave frequency region. At the GHz frequencies, the relative dielectric constant of coal is slightly higher for the E-field parallel to the layers than for the perpendicular case. The coal did not absorb as much water as anticipated, thus there was not a significant change in the properties of wet and dry coal for these particular samples.

DIELECTRIC CONSTANT AND LOSS TANGENT DATA (SAMPLES AS RECEIVED)

Material	1 MHz		10 MHz		100 MHz		1 GHz		2 GHz		10 GHz	
	ε_r	Tan δ	ε_r	Tan δ	ε_r	Tan δ	ε_r	Tan δ	ε_r	Tan δ	ε_r	Tan δ
Slate			14.1	0.67	7.4	0.46	7.25	0.023	7.4	0.010	7.4	0.025
			14.4	0.83	6.9	0.57	7.30	0.016	7.4	0.016	7.3	0.030
			14.6	0.85	7.4	0.57	7.40	0.025	7.3	0.032	7.28	0.034
Shale	5.60	0.30	5.6	0.21	4.03	0.16	4.05	0.05	4.03	0.04	5.55	0.05
	5.58	0.25	5.4	0.17	4.83	0.17	5.59	0.009	5.62	0.20	5.61	0.06
	5.50	0.26	5.3	0.25	3.48	0.13	4.29	0.032	3.96	0.02	5.43	0.04
Sandstone	5.64	0.13	4.9	0.08	4.5	0.05	4.28	0.04	4.17	0.03	4.16	0.02
	6.13	0.01	6.07	0.006	6.0	0.09	4.29	0.032	4.15	0.03	4.14	0.02
	6.05	0.007	6.01	0.008	5.8	0.06	4.26	0.04	4.16	0.03	4.16	0.02
Coal	4.10	0.25	4.7	0.10	3.75	0.09	4.1	0.06	4.85	0.06	3.70	0.06
	3.93	0.18	4.0	0.09	4.20	0.07	4.0	0.04	3.80	0.06	3.71	0.05
	3.84	0.21	5.2	0.10	3.99	0.07	5.1	0.06	3.79	0.04	4.71	0.04

TABLE I

DIELECTRIC CONSTANT AND LOSS TANGENT DATA OF COAL SAMPLES

Material	1 MHz		10 MHz		100 MHz		1 GHz		2 GHz		10 GHz	
	ε_r	Tan δ	ε_r	Tan δ	ε_r	Tan δ	ε_r	Tan δ	ε_r	Tan δ	ε_r	Tan δ
Coal (Parallel As Received)	3.63	0.25	3.5	0.10	2.90	0.09	4.18	0.06	3.87	0.06	3.80	0.05
Coal (Perpendicular As Received)	7.6	0.61	6.1	0.07	5.1	0.08	4.05	0.06	3.76	0.06	3.62	0.03
Coal (Parallel-Wet)	3.91	0.44	5.8	0.29	4.7	0.1	3.56	0.08	3.8	0.09	4.0	0.05
Coal (Perpendicular-Wet)	7.8	0.5	6.3	0.23	4.9	0.16	3.68	0.08	3.85	0.08	3.7	0.09
Coal (Parallel-Dry)	3.1	0.14	4.6	0.16	4.4	0.08	4.05	0.05	3.7	0.03	3.69	0.02
Coal (Perpendicular-Dry)	3.2	0.1	4.8	0.06	4.7	0.06	3.5	0.03	3.51	0.008	3.4	0.02

TABLE II